Observations of the Inner-Core Structure of Rapidly Intensifying Tropical Cyclones

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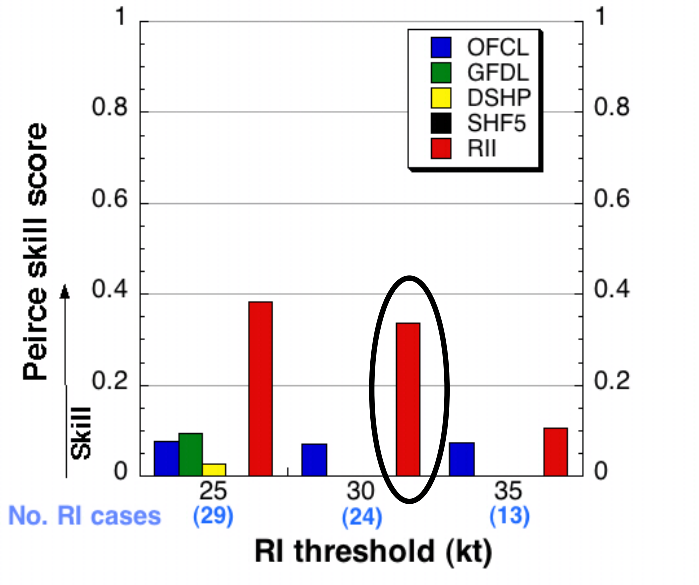
Motivation

- Advances in forecasts of tropical cyclone (TC) intensity, and rapid intensity change (RI) in particular, lag advances in TC track forecasts
- Multiscale interactions major reason for this – environmental to microscale
- RI forecasts (e.g., RI index) based largely on environmental-scale fields generally explain about 35% of skill in RI forecasts



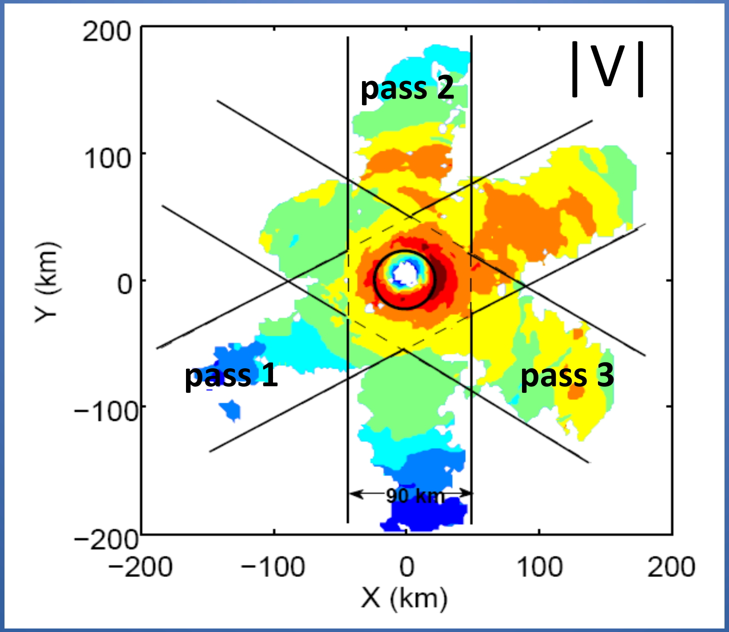
(from Kaplan et al. 2009)

<u>Questions to consider</u>

- *To what extent can processes smaller than the environmental scale explain remainder of skill?*
- *Are there differences detectable in smaller-scale structures that may differentiate intensifiers from non-intensifiers?*

Kinematic structure from airborne Doppler radar

- Automatic data QC: HRD real-time procedure
  (www.nhc.noaa.gov/jht/2003-2005reports/DOPLRgamache_JHTfinalreport.pdf)
- Analyze wind & reflectivity for each eyewall pass (Gamache 1997; Reasor et al. 2009)
  - 2 km horizontal spacing; 0.5 km vertical spacing
- Merge analyses of eyewall passes for each flight to create an Intensive Observing Period, or "IOP"
- Complete radar database: 261 eyewall passes in 77 IOP's from 19 different TC's provide "snapshots" of inner-core structure



Wind speed from IOP centered at 00 UTC Aug. 30 in Hurricane Earl

Dataset and analysis technique

- Sample radar database to extract flights associated with TC's that are "Rapidly Intensifying" (RI) and "Steady-State" (SS)
  - intensification rate equivalent to 20 kt / 24 h (RI) and +/- 10 kt / 24 h (SS)
  - criteria for inclusion: at least hurricane strength, at least 25 kt below MPI, at least 100 km from land, data out to at least 1.5 x RMW

RI

Storm Name	Dates	Number of passes	Number of IOP's
Ophelia	13 Sep 2005	2	1
Gustav	29-30 Aug 2008	4	2
Earl	29 Aug - 1 Sep 2010	13	4
Ivan	7 Sep 2004	4	1
Paloma	7 Nov 2008	8	2
Guillermo	2 Aug 1997	4	2
Felix	1 Sep 2007	2	1
Katrina	27 Aug 2005	3	1

40 eyewall passes from 14 IOP's in 8 TC's

SS

Storm Name	Dates	Number of passes	Number of IOP's
Gustav	31 Aug 2008	10	2
Frances	30 Aug - 4 Sep 2004	8	3
Ophelia	11 Sep 2005	2	1
Ivan	14 Sep 2004	6	1
Jeanne	24 Sep 2004	6	2
Ike	10-12 Sep 2008	19	4

53 eyewall passes from 14 IOP's in 6 TC's

- Composite merged analyses (for vortex scale) and individual eyewall passes (for convective scale) based on radius of maximum axisymmetric wind (RMW) at 2 km altitude as in Rogers et al. (2012)

- Focus on symmetric and asymmetric vortex structure, convective structure

Some database properties

		best track intensity at time of IOP (kt)	2-km axisymmetric RMW (km)	850-200 SHIPS-derived shear mag (kt)	850-500 SHIPS-derived shear mag (kt)	SST from SHIPS (deg C)
RI	mean	88.6	43.0	11.2	**5.0****	**29.5****
	standard deviation	18.9	23.6	5.4	3.0	0.5
SS	mean	90.4	52.5	12.3	**8.0****	**29.2****
	standard deviation	13.2	19.8	5.5	4.4	0.6

**** denotes differences significant at 95% confidence level**

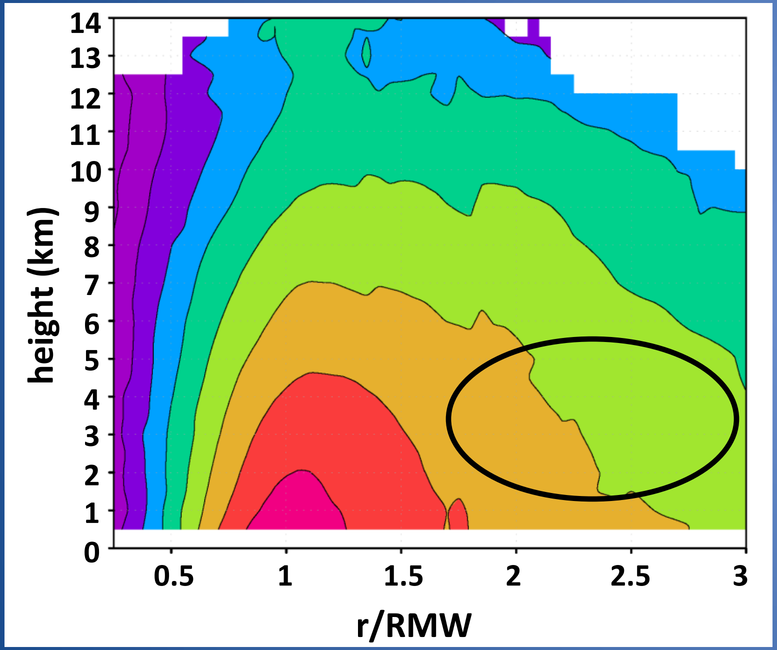
- no significant differences in intensity and size of storm, deep-layer shear

Symmetric vortex structure

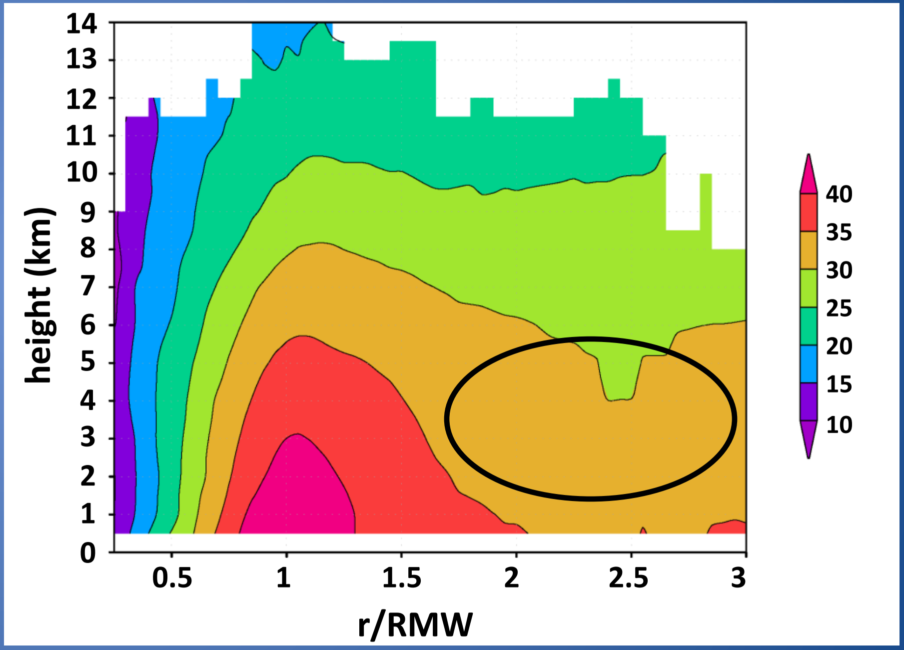
Tangential wind ($m\ s^{-1}$)

*minimum of 8 Intensive Observing Periods (IOPs) required for plotting

RI



SS



RI cases show (significant at 95% confidence level):

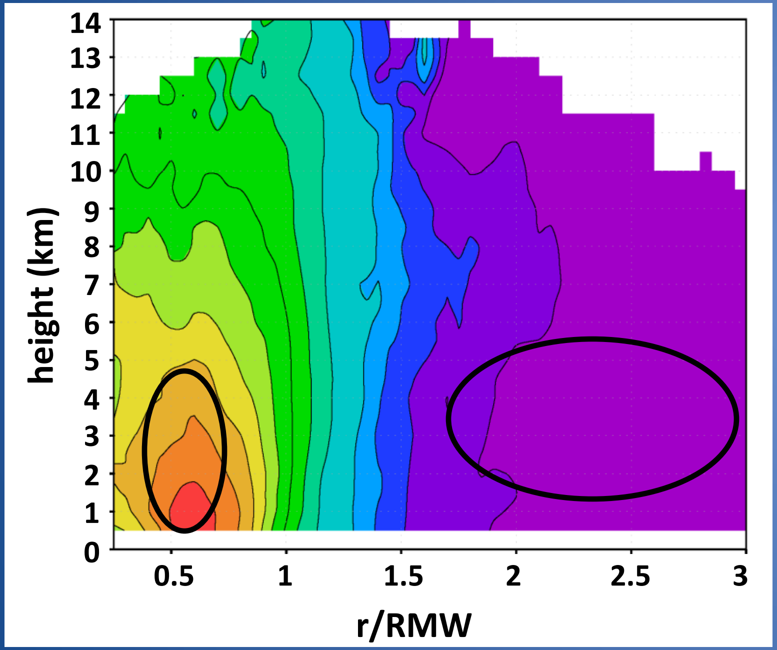
- weaker wind field in outer core

Symmetric vortex structure

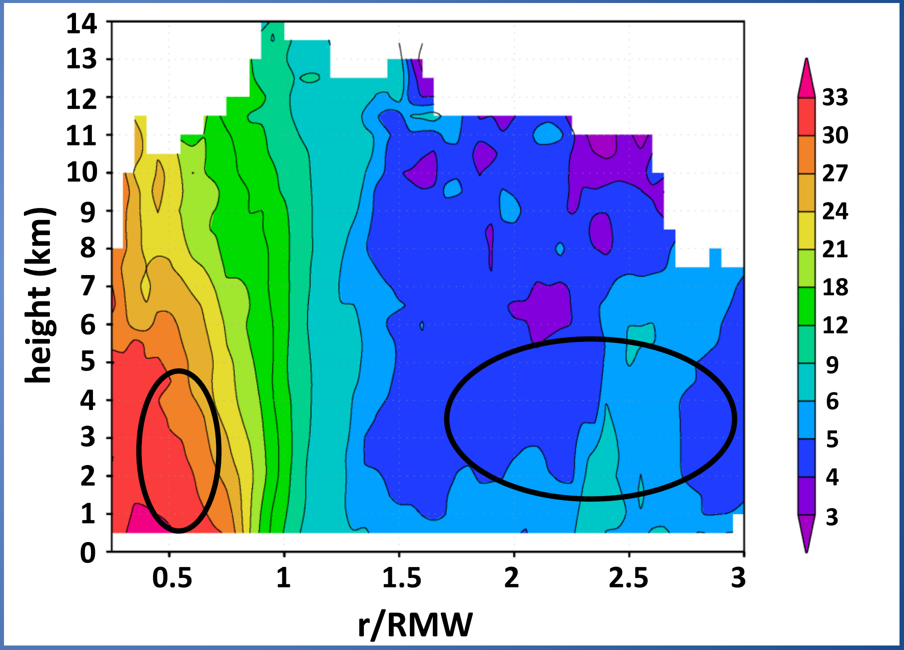
Vertical vorticity (x 10^{-4} s^{-1})

*min. 8 IOPs required for plotting

RI



SS



RI cases show (significant at 95% confidence level):

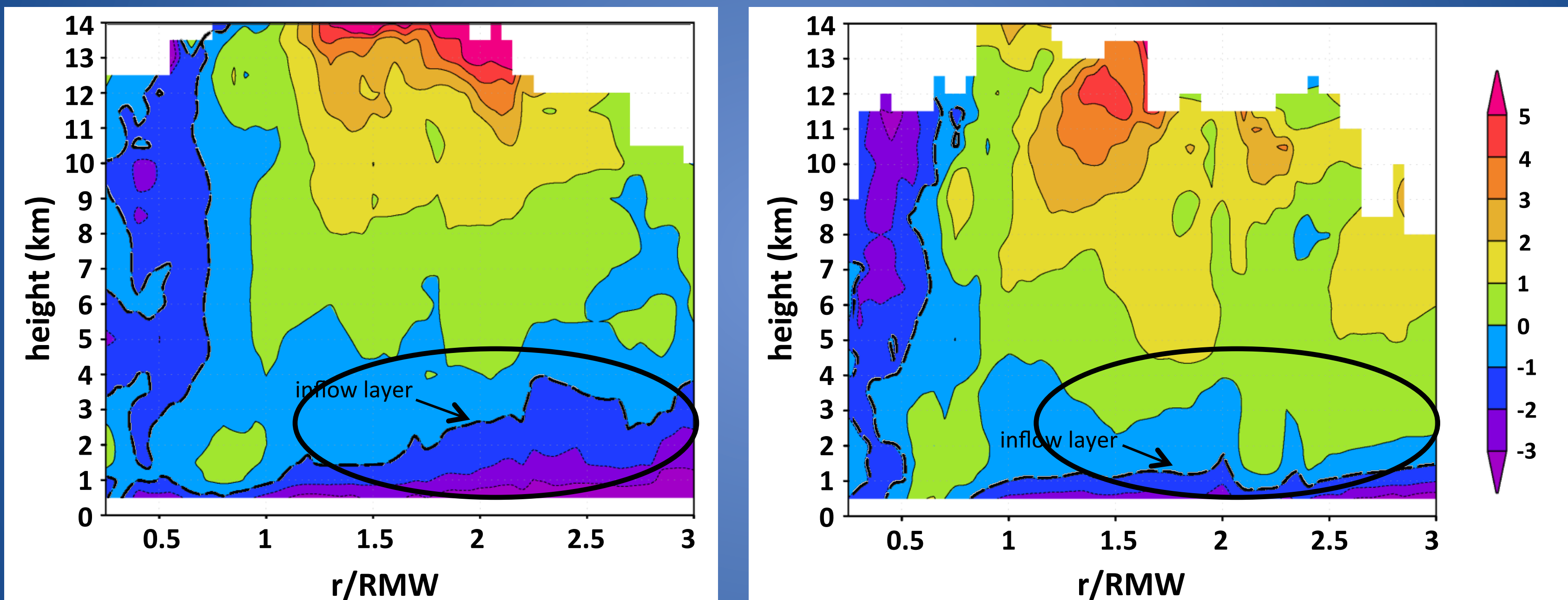
- more ring-like vorticity structure inside eyewall
- lower outer-core vorticity

Symmetric vortex structure

Radial wind (m s^{-1})

*min. 8 IOPs required for plotting

RI SS



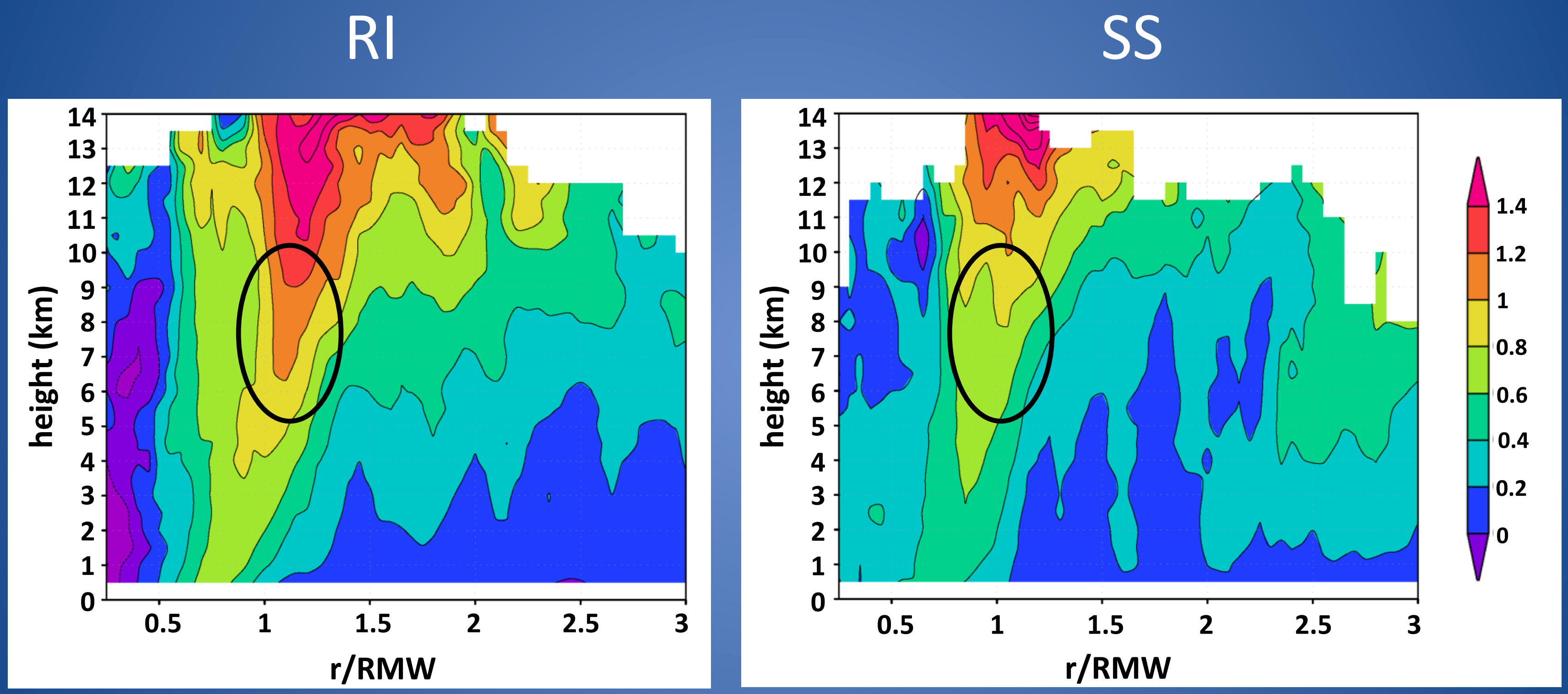
RI cases show (significant at 95% confidence level):

- deeper inflow layer outside RMW

Symmetric vortex structure

Vertical velocity (m s^{-1})

*min. 8 IOPs required for plotting



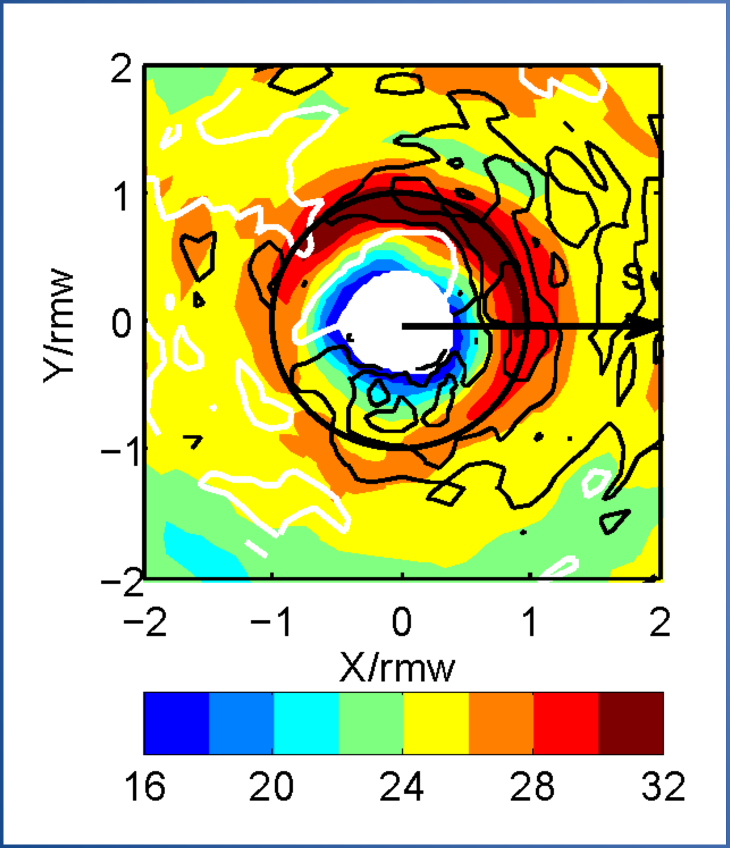
RI cases show (significant at 95% confidence level):

- stronger symmetric eyewall updraft above 6 km

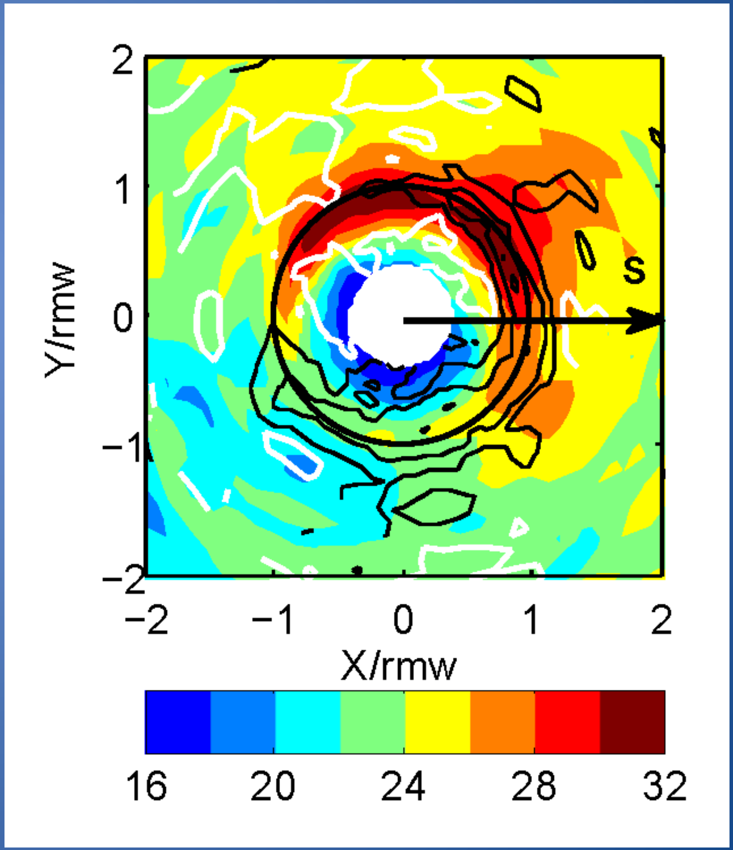
Asymmetric vortex structure

Shear-relative reflectivity (shaded, dBZ) and vertical velocity (contour, m s^{-1}) at 2 km

RI



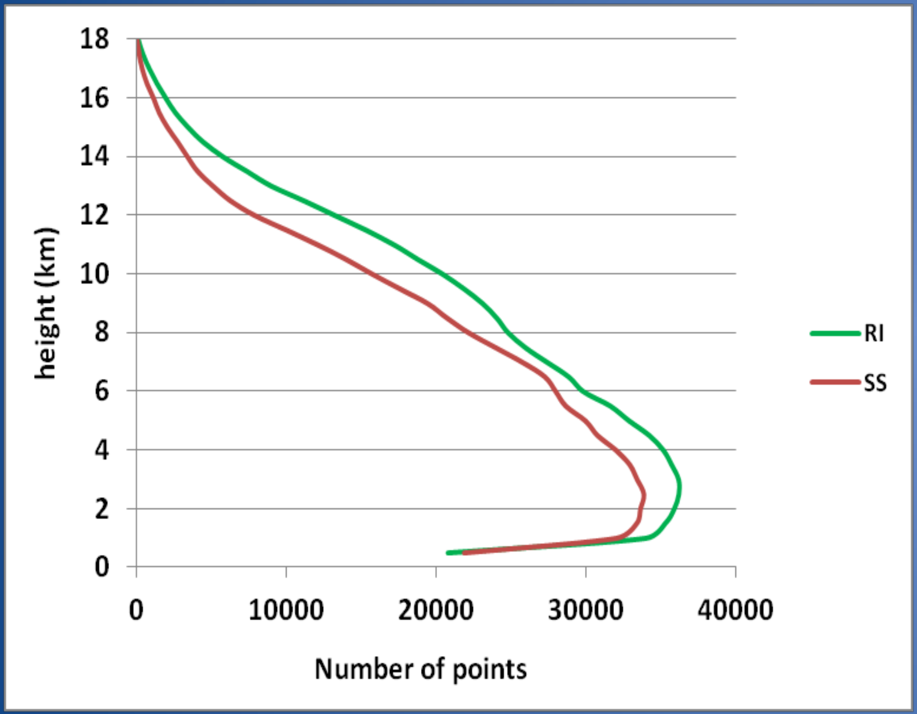
SS

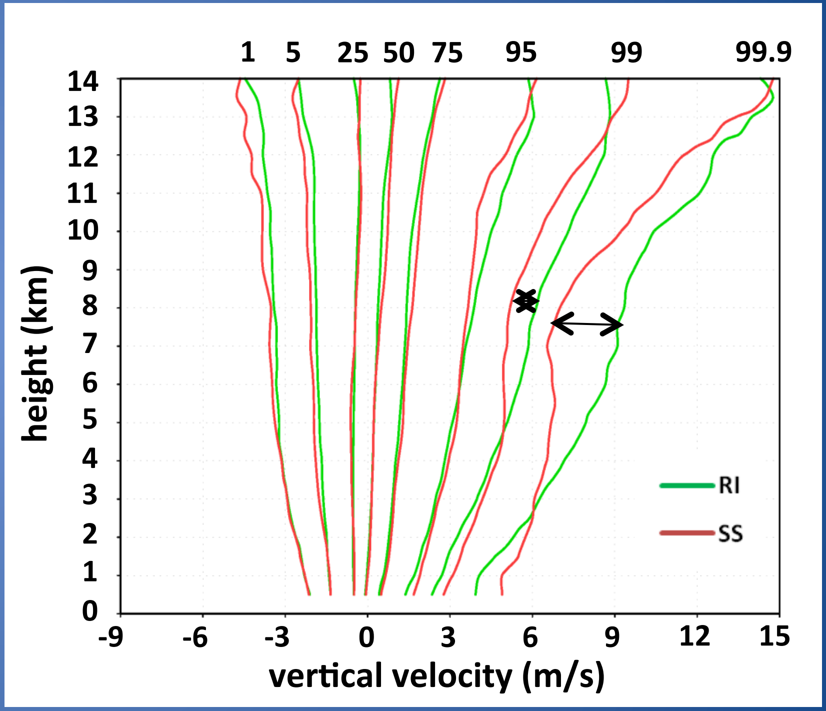


RI cases show:

- greater azimuthal coverage of eyewall reflectivity

Convective structure





RI cases show

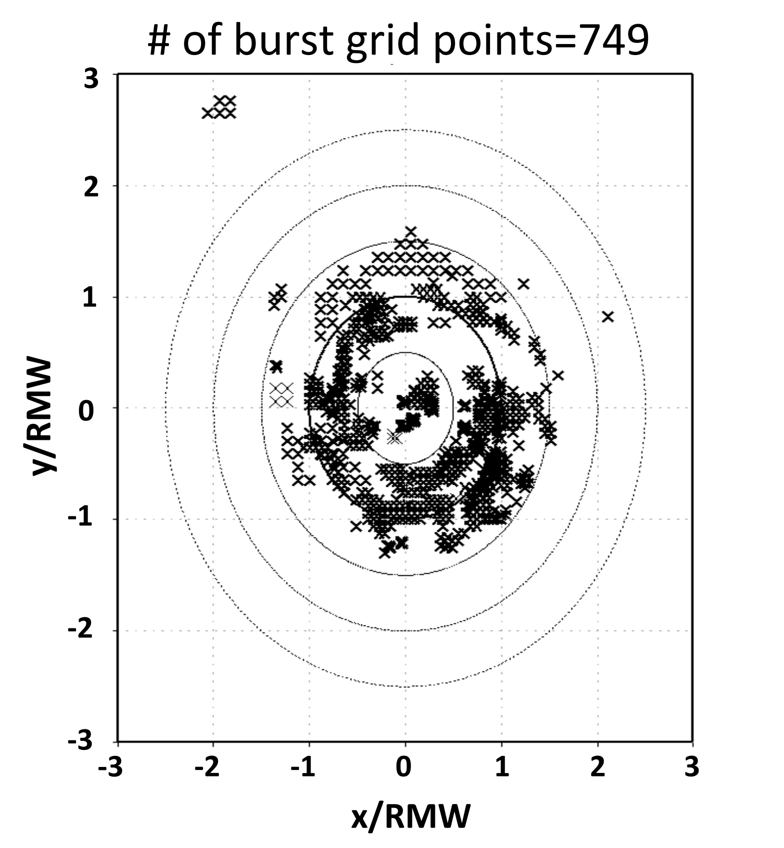
- stronger updrafts above freezing level for extreme portions of updraft spectrum (top 1% and greater)
- no significant differences in profiles for weaker portions of spectrum, or for downdrafts

Convective structure

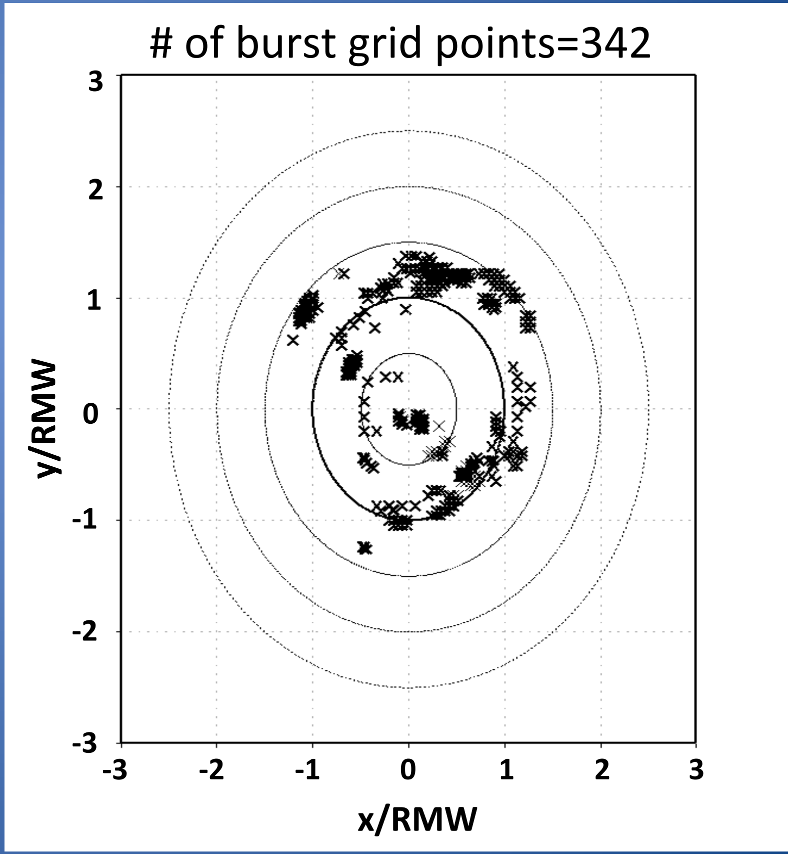
Number and location of convective bursts

Bursts defined as locations where w > 5.5 m/s at 8 km altitude (top 1% of w)

RI



SS

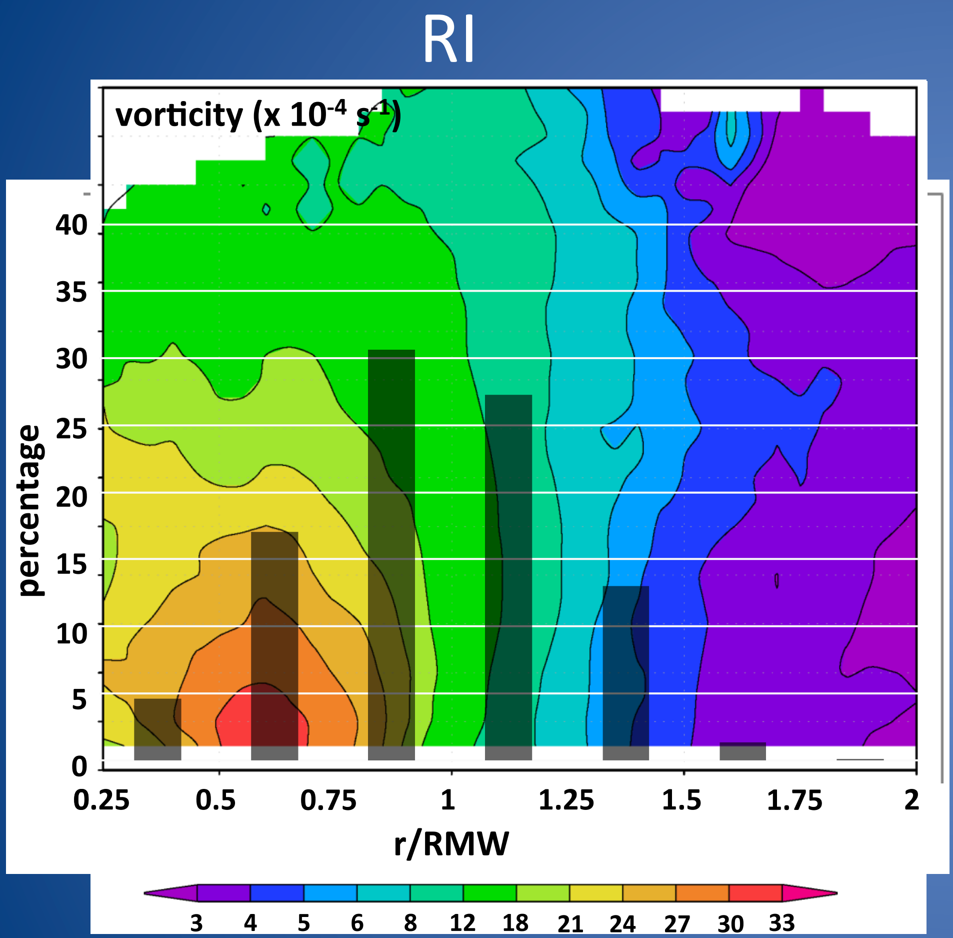


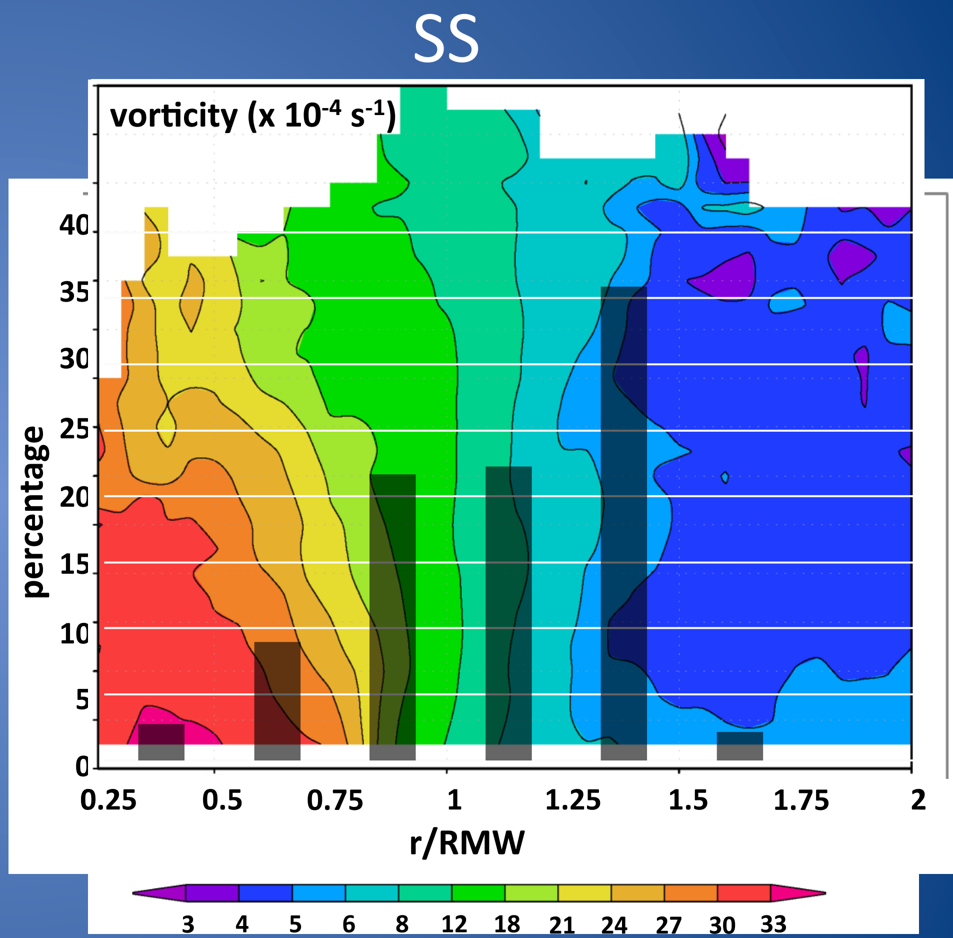
RI cases show

- more convective bursts

Convective structure

Radial distribution of convective bursts



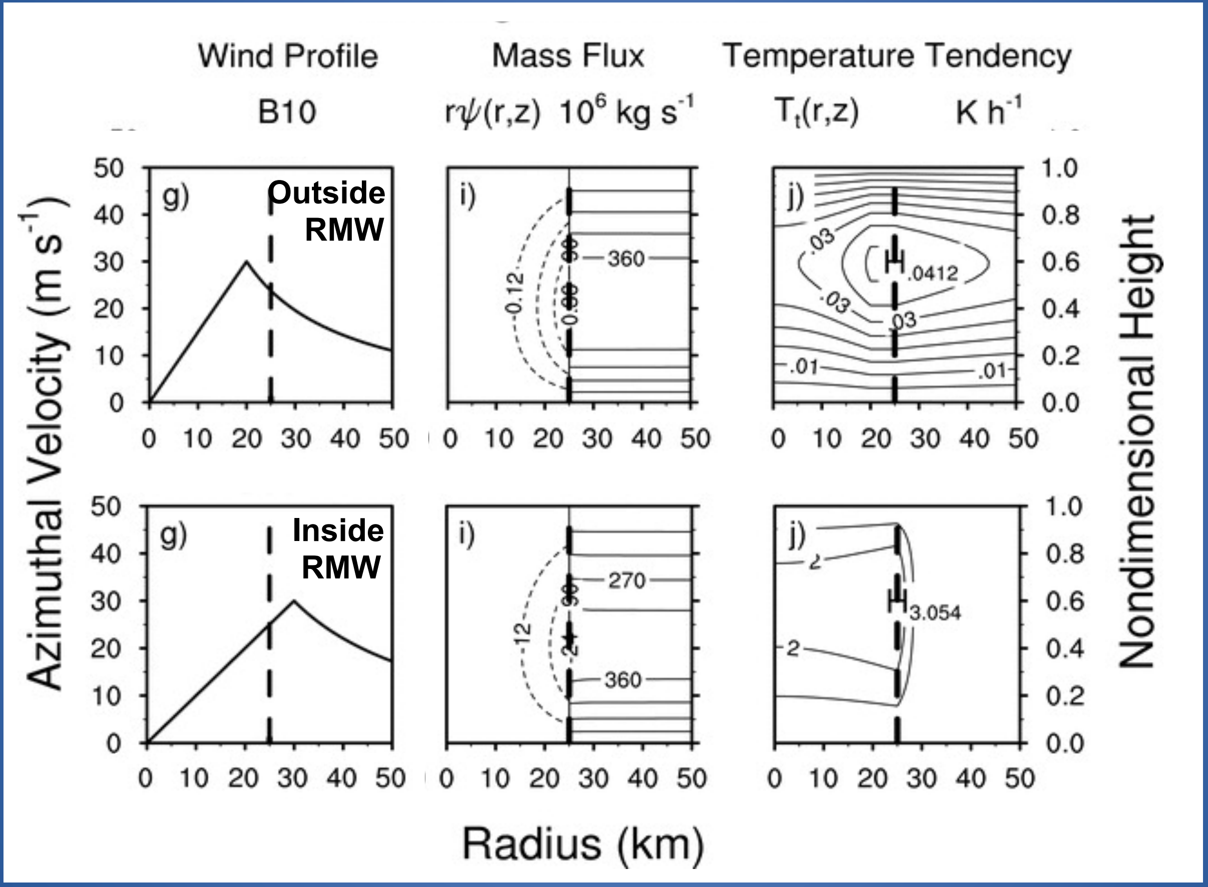


RI cases show

- radial distribution of convective bursts that peaks inside RMW compared with outside RMW for SS cases

Convective structure

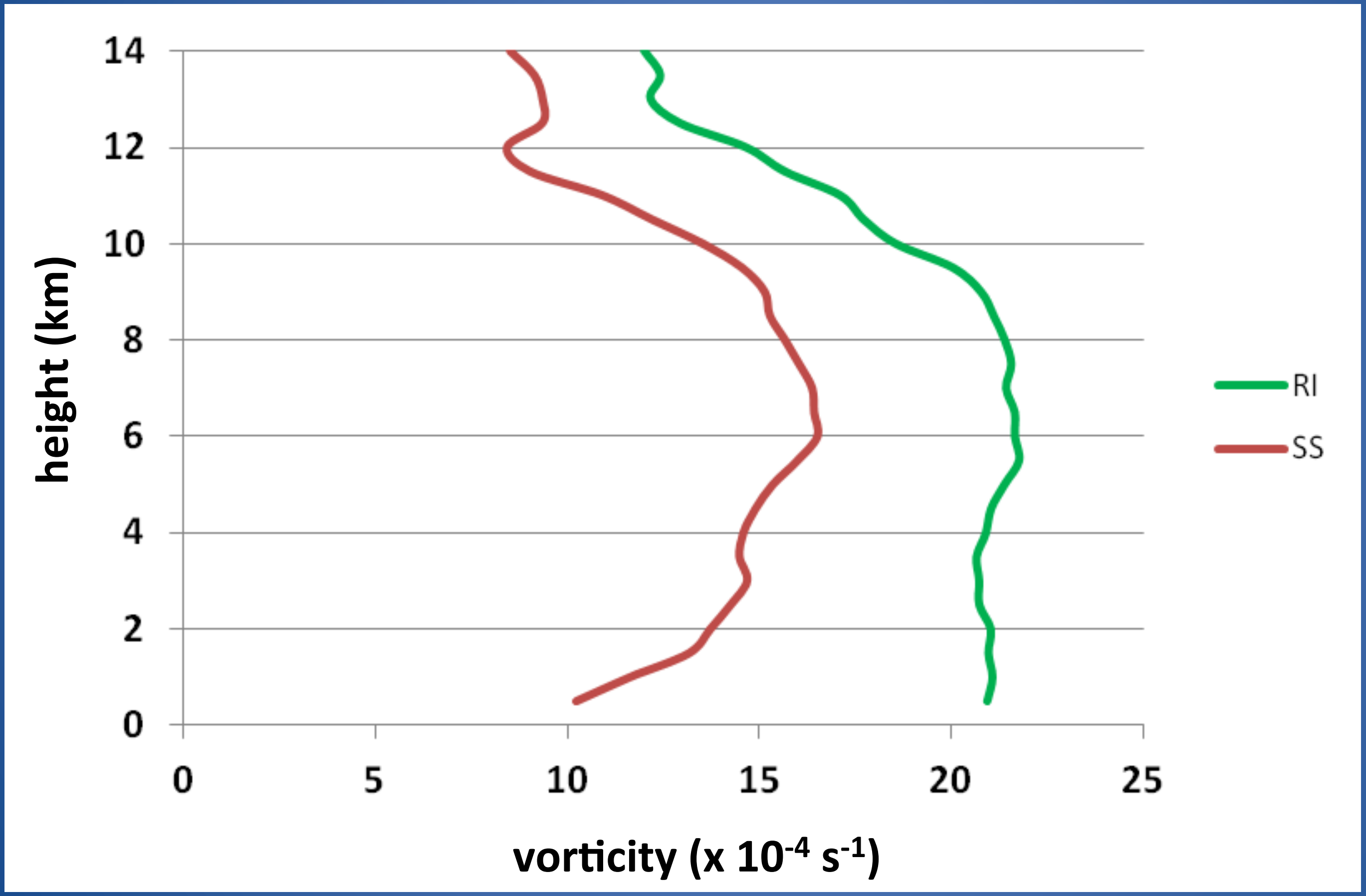
Radial distribution of diabatic heating



(adapted from Vigh and Schubert, 2009)

Convective structure

Mean profiles of vorticity of eyewall convective bursts (10-km radius average)



RI cases show

- higher vorticity associated with convective bursts

Summary

- Compared to steady-state storms, rapid intensifiers have:
  - ring-like vorticity structure inside eyewall
  - lower inertial stability in outer core
  - deeper inflow layer
  - stronger and deeper secondary circulation
  - greater azimuthal symmetry in eyewall rainfall
  - more and stronger convective bursts in more favorable radial location for vorticity amplification
  - higher burst vorticity – more/stronger vortical hot towers?
- Caveats in analysis
  - Intensity history and secondary eyewalls in SS cases
  - sample size and coverage limitations

Future Work

- Expand sample size, add tropical storms
- Examine boundary layer kinematic structural differences
- Add dropsondes for thermodynamic analysis
- Examine serial IOPs for temporal evolution(e.g., Earl 2010, Ophelia 2005)
- Test relationships in numerical models

How HS3 can help this research

- Additional cases of inner-core structure
- Additional data sets
  - Upper-level thermodynamic structure and evolution from HAMSR – warm core development during RI
  - Three-dimensional winds from HIWRAP – symmetric (maybe asymmetric?) vortex structure and burst statistics
  - Surface wind field structure and evolution from HIRAD
  - Environmental measures of winds, temperature and humidity from dropsondes
- Greater temporal coverage of specific RI cases

NOAA IFEX plans for 2012 Hurricane Season

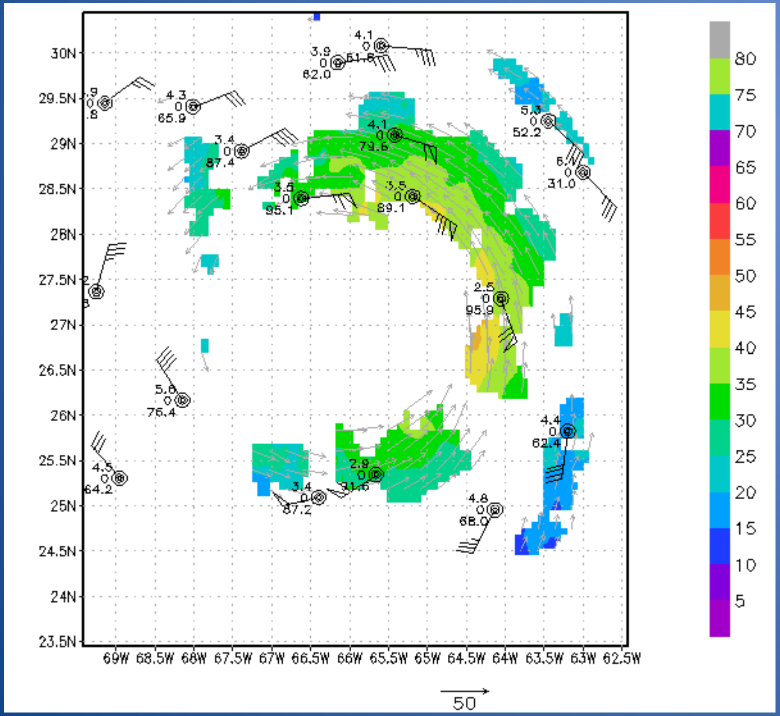
- G-IV and one P-3 available
  - 195 G-IV hours, 150 P-3 hours
  - Doppler radar on G-IV
- Continue addressing IFEX/HFIP goals
- Sustain our partnerships with EMC and NHC
- Interact with NASA during their HS3 field campaign
- Encourage greater awareness in broader TC community (e.g., social media)

First-look at G-IV TDR

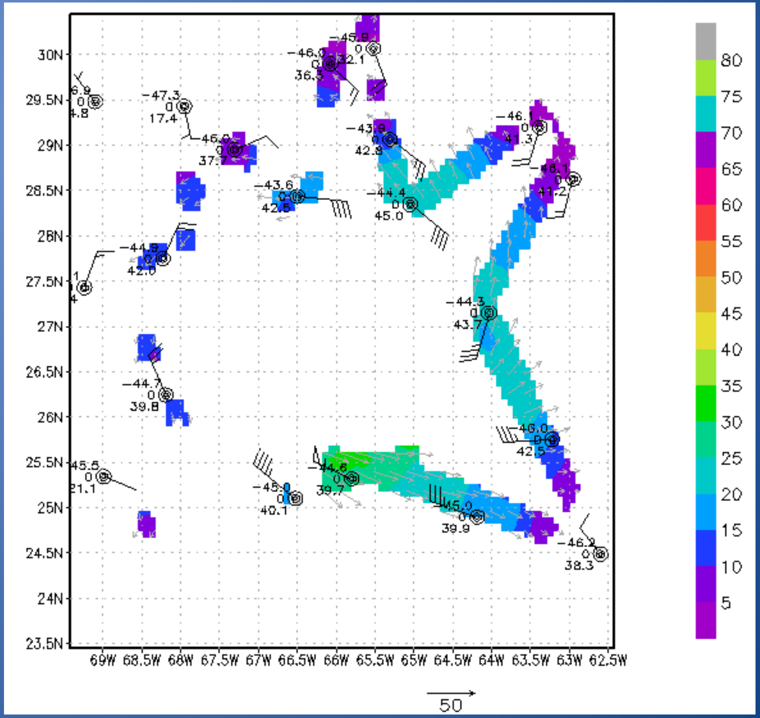
Hurricane Katia (2011)

Doppler-derived wind speed (shaded, m s^{-1}) and dropsonde measurements from G-IV flight centered at 00 UTC Sept. 6 2011

4 km



12 km

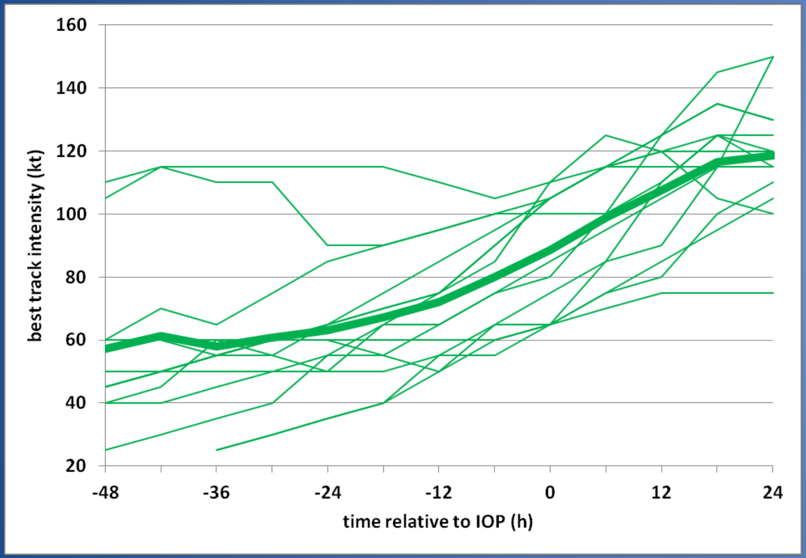


Extra slides

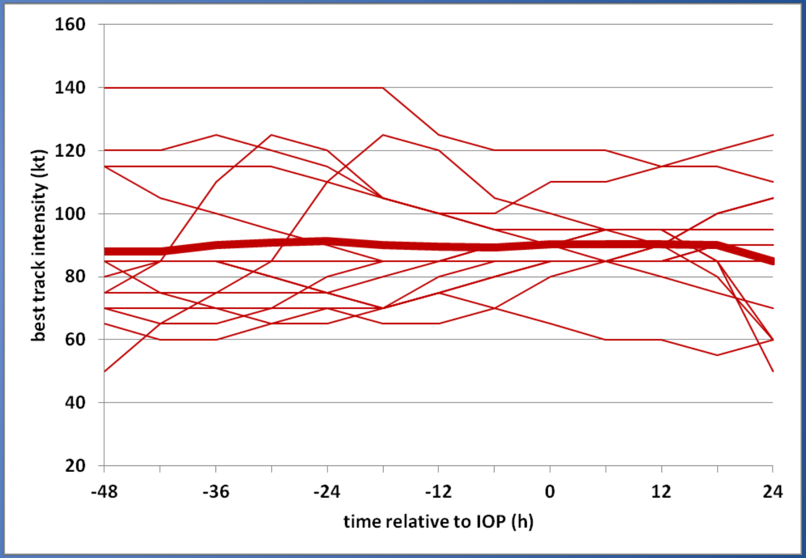
Some database properties

Best track intensity history for each IOP (thick line is mean)

RI



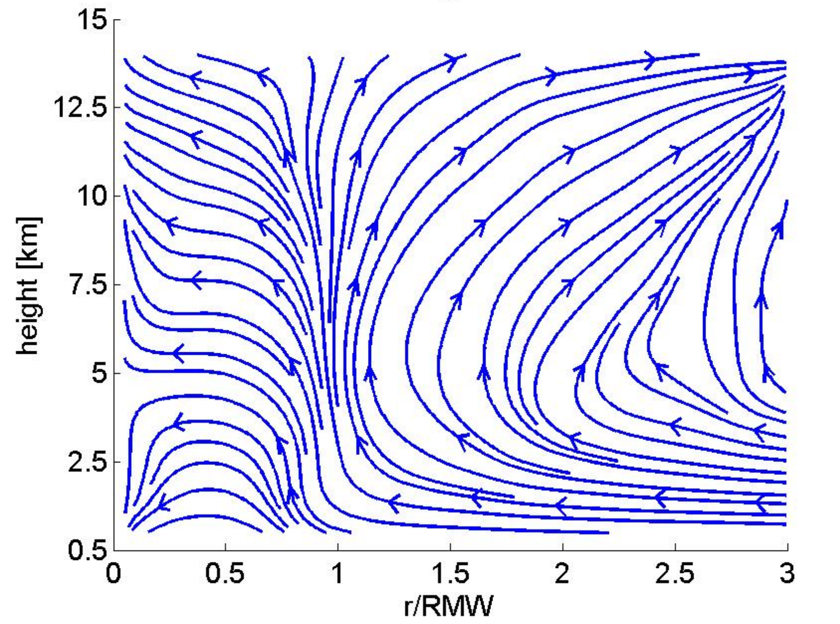
SS



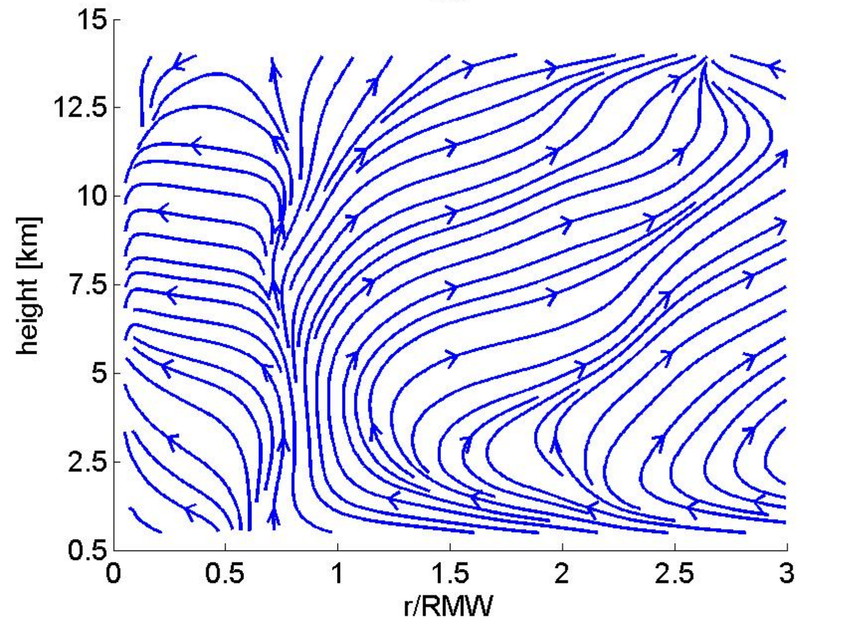
Symmetric vortex properties

Streamlines of secondary circulation

RI



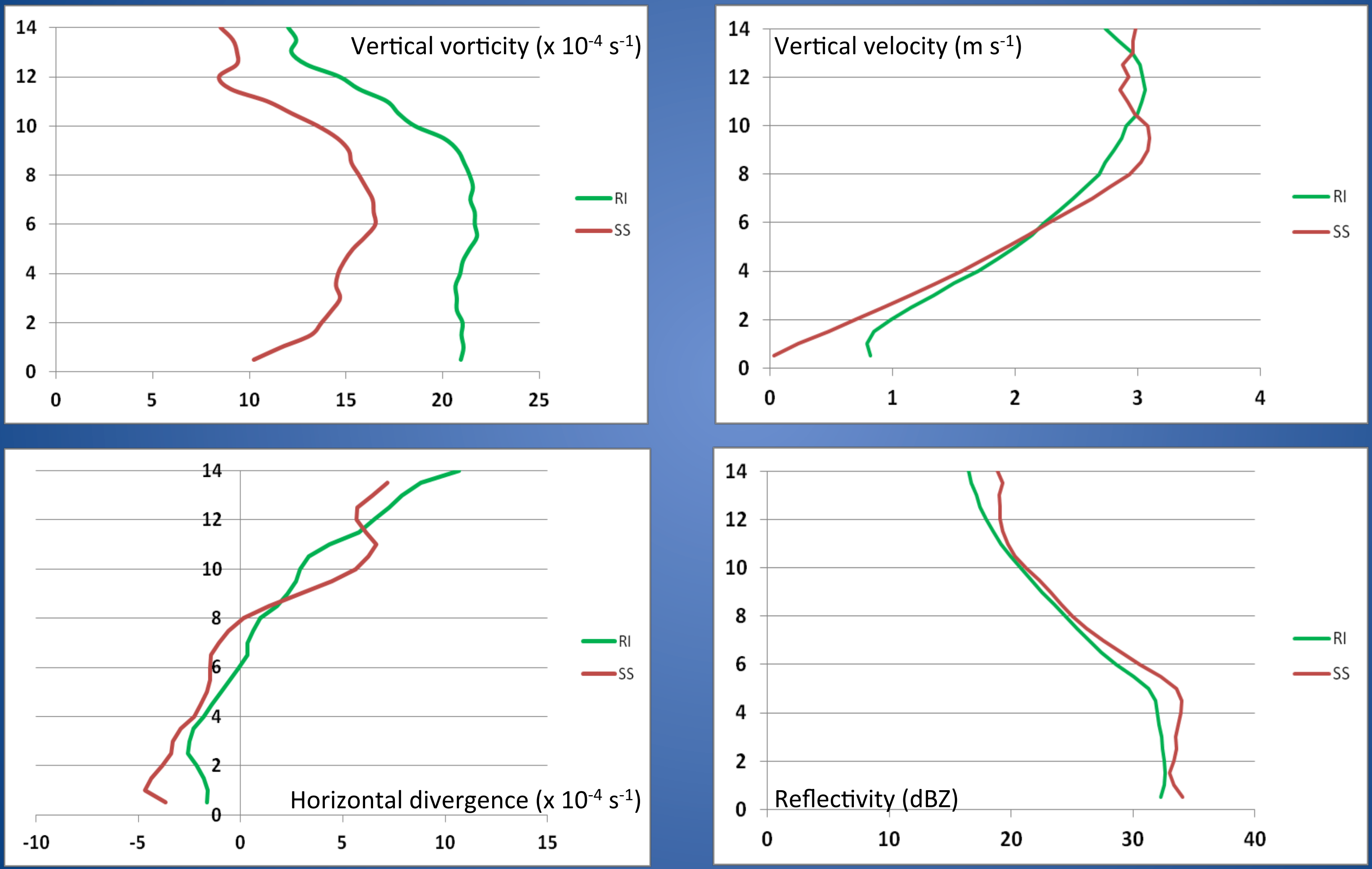
SS



- RI cases have deeper inflow, deeper secondary circulation

Convective-scale statistics

Mean profiles of eyewall convective bursts (10-km radius average)



- higher vorticity for bursts in RI cases, little difference in other fields